The ARPA-E RANGE Program
-Driving Vehicle Level Performance

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Support Contractor to ARPA-E

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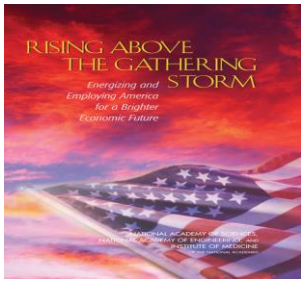
Transformative Vertical Flight Workshop
NASA Ames Research Center
Moffett Federal Airfield, CA

ARPA-E's History

In 2007, The National Academies recommended Congress establish an Advanced Research Projects Agency within the U.S. Department of Energy*



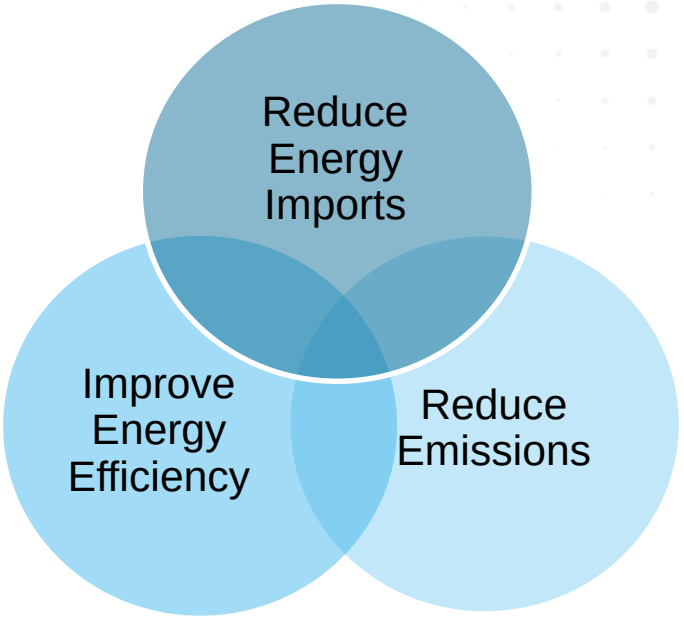
…"The new agency proposed herein [ARPA-E] is patterned after that model [of DARPA] and would sponsor creative, out-of-the-box, transformational, generic energy research in those areas where industry by itself cannot or will not undertake such sponsorship, where risks and potential payoffs are high, and where success could provide dramatic benefits for the nation."…

ARPA-E Authorizing Legislation

Mission: To overcome long-term and high-risk technological barriers in the development of energy technologies

Goals: **Ensure America's**

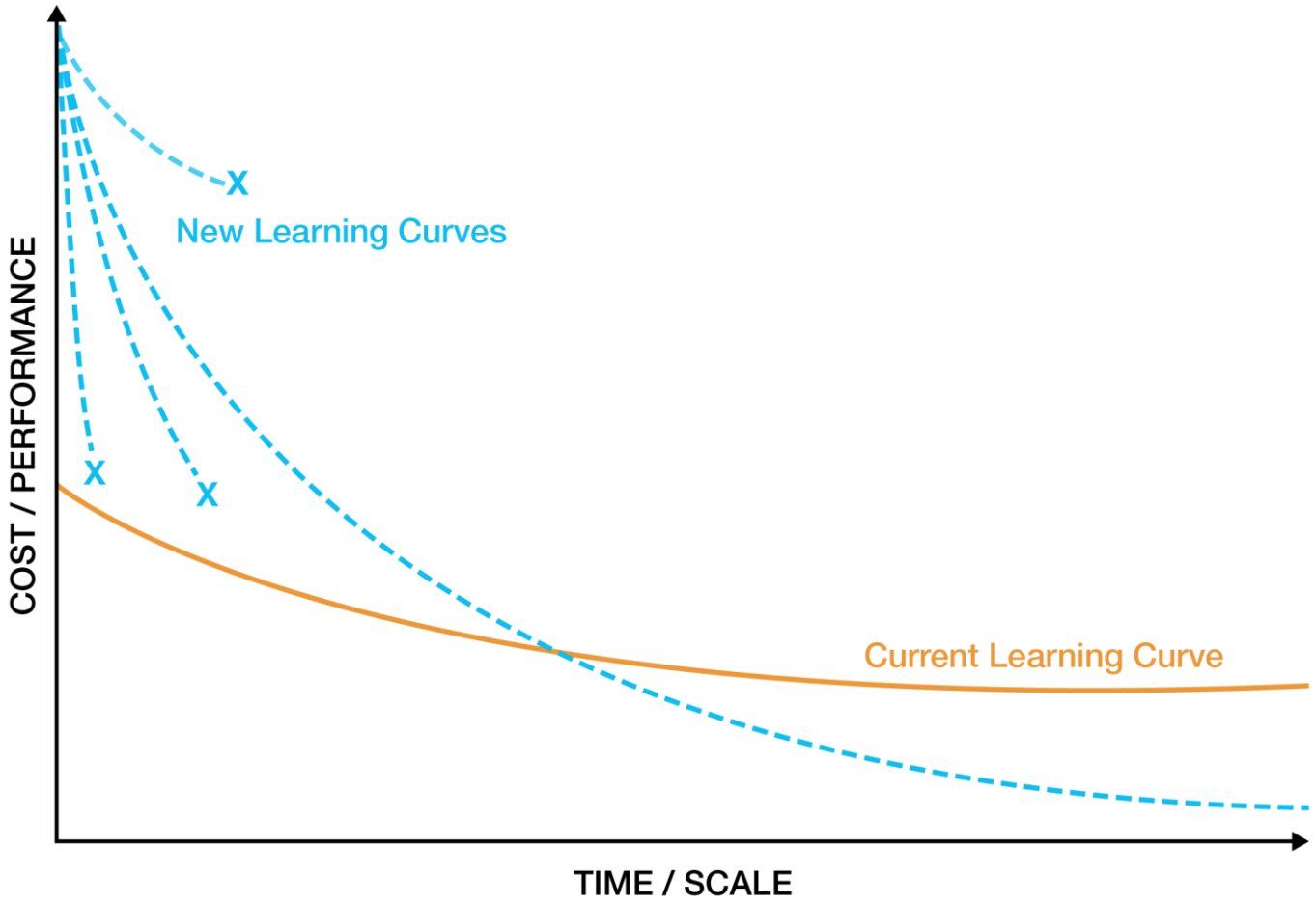
- Economic Security
- Energy Security
- Technological Lead in Advanced Energy Technologies



Means:

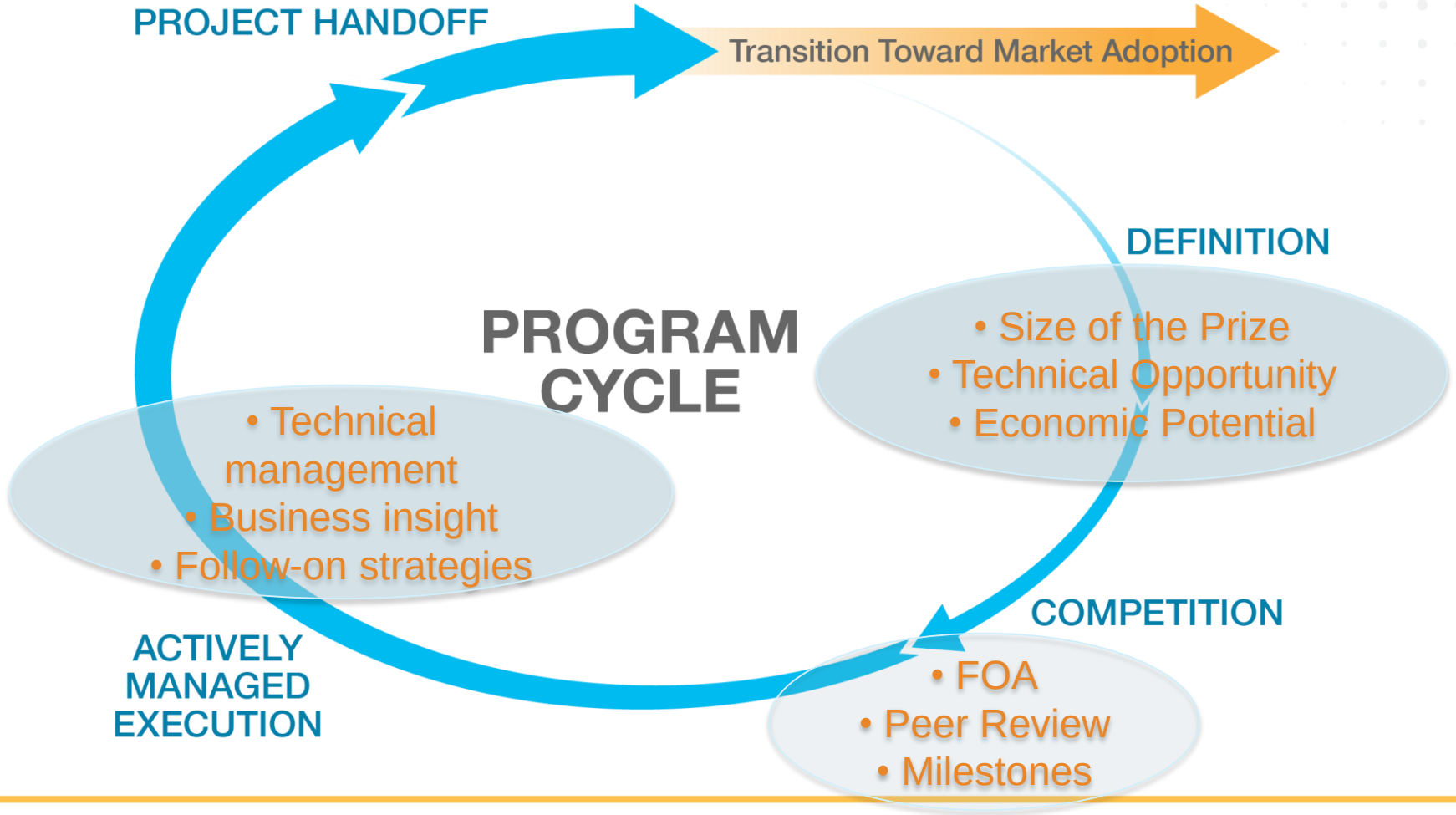
- Identify and promote revolutionary advances in fundamental and applied sciences
- Translate scientific discoveries and cutting-edge inventions into technological innovations
- Accelerate transformational technological advances in areas that industry by itself is not likely to undertake because of technical and financial uncertainty

Creating New Learning Curves



ARPA-E Process

ARPA-E Program Directors and Tech-to-Market Advisors develop programs and guide project teams



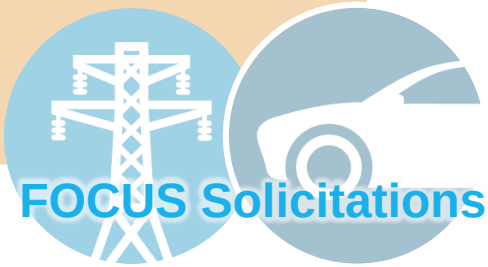
Programs

OPEN programs support the development of potentially disruptive new technologies across the full spectrum of energy applications.

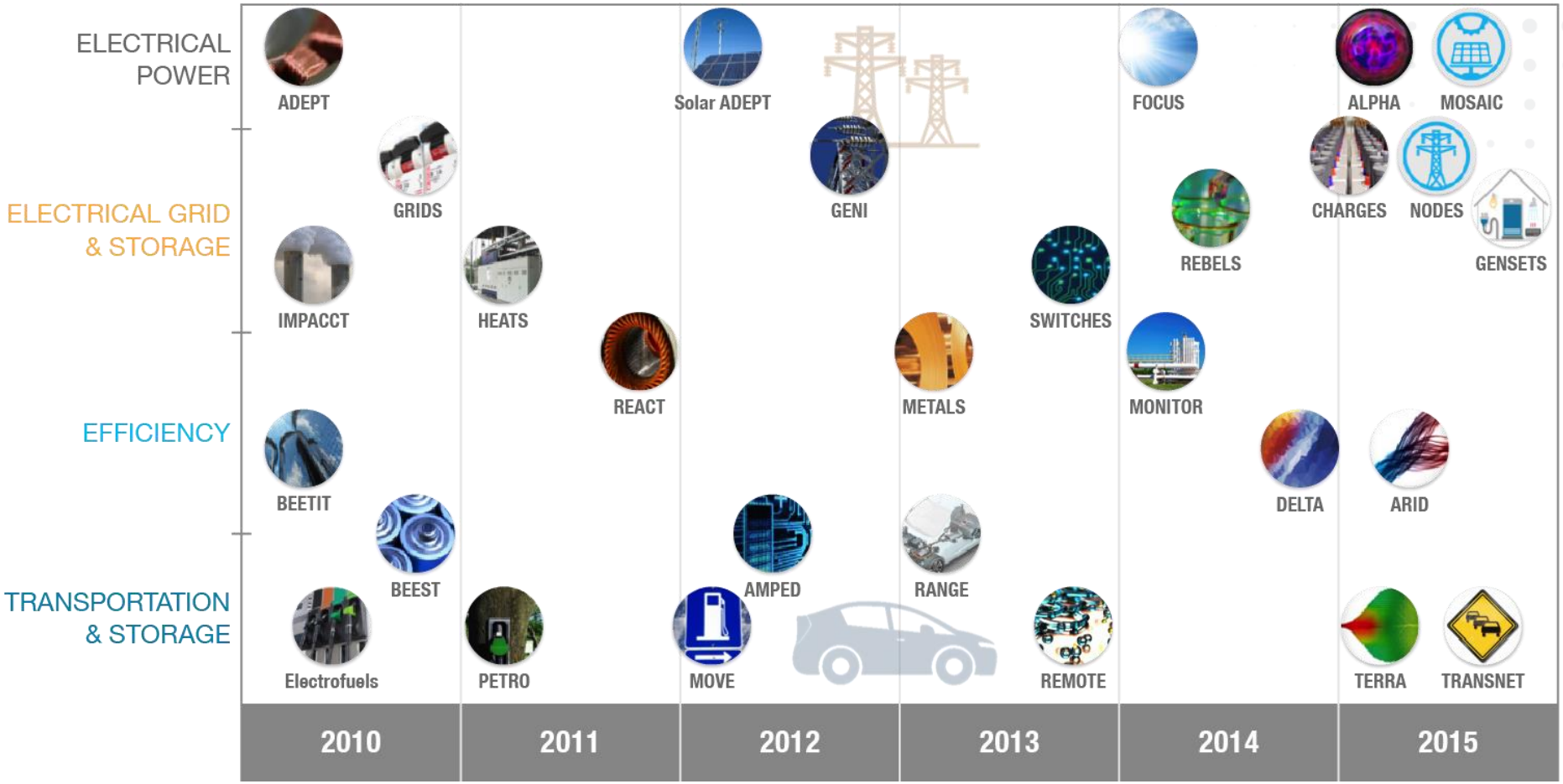
- Complement focused programs
- Support innovative “one off” projects
- Provide a “snapshot” of energy R&D

FOCUS programs identify R&D topics by potential to make a significant difference in ARPA-E’s mission space.

- Size of the potential impact
- Technical opportunities for transformation
- Portfolio of projects with different approaches



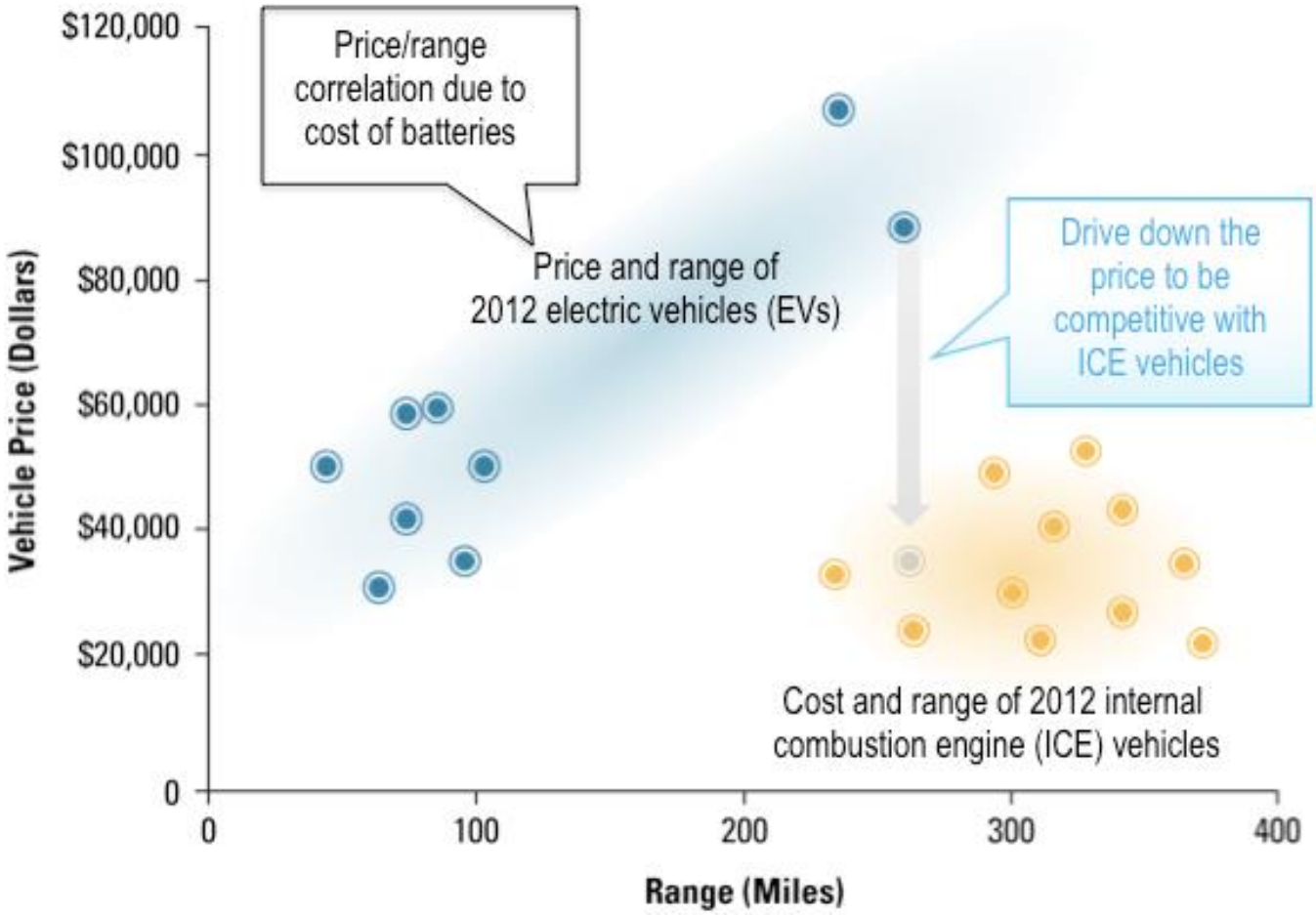
Focused Program Portfolio



RANGE:
Robust Affordable Next Generation EV-Storage

RANGE Program by Ping Liu – ARPA-E Program Director

Motivation: EVs Competitive with ICE Vehicles in Cost and Range



Battery cost reduction is critical to reduce costs of EVs

A System Perspective to EV Battery Cost Reduction

Vehicle battery cost per mile of range:

$$\$_{battery}/mile = (\$_{battery\text{-}cell} * pack\text{-}overhead)/kWh \times kWh/mile$$

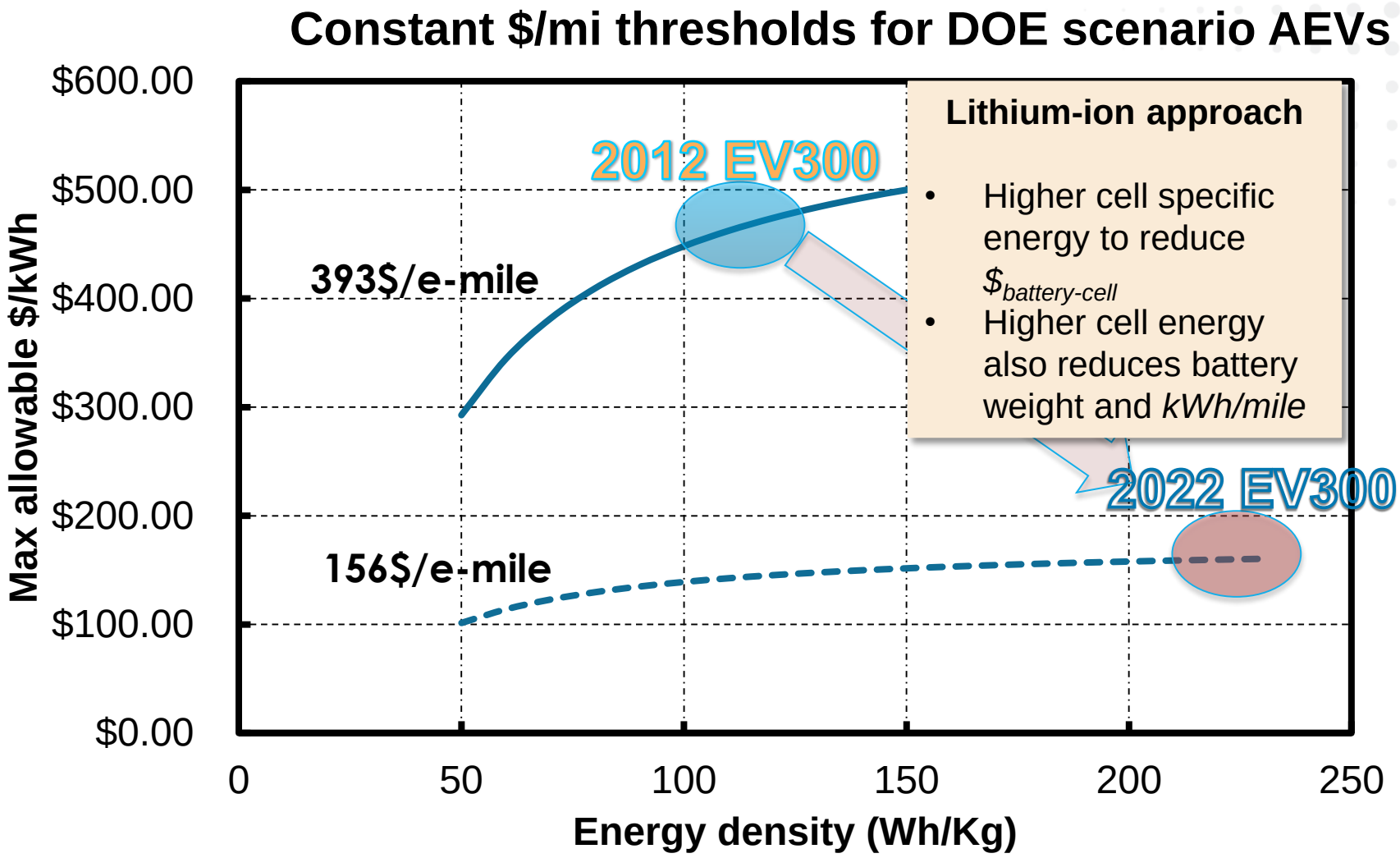
Cost

Performance
Abuse tolerance

Weight

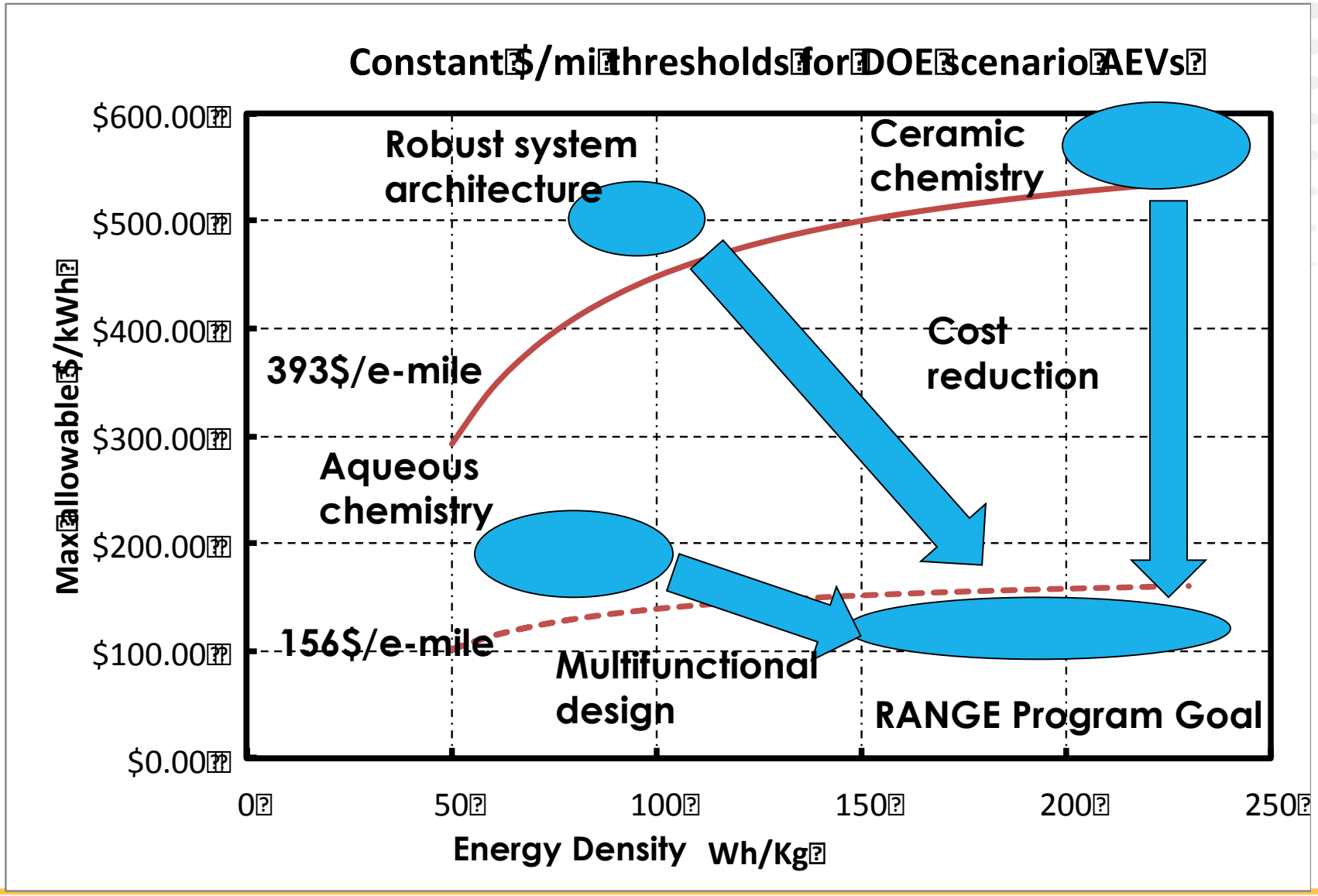
Battery + rest of vehicle

The Lithium Ion Path Towards a Low Cost EV

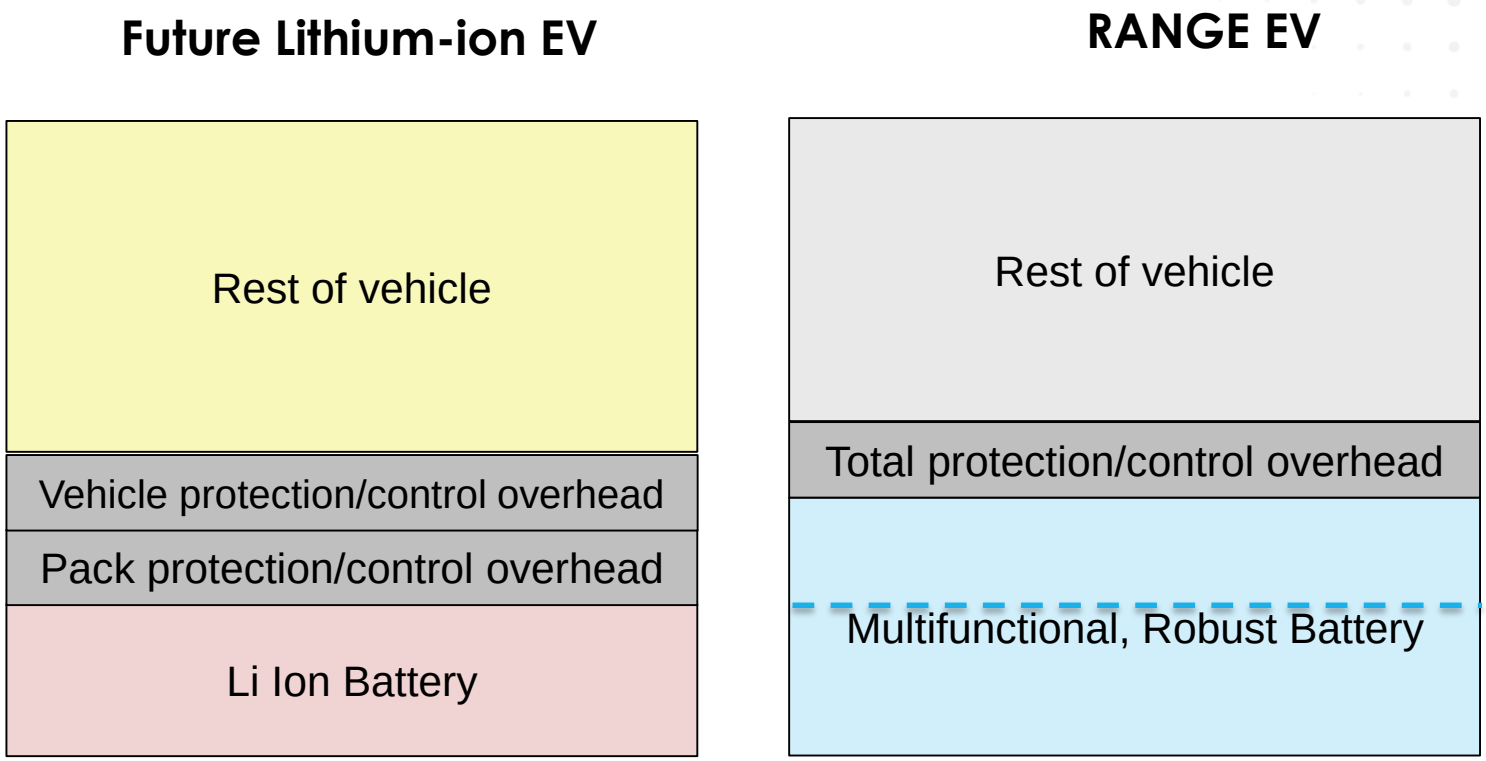


Thanks to input from J. Ward

Paths towards a robust, low cost EV

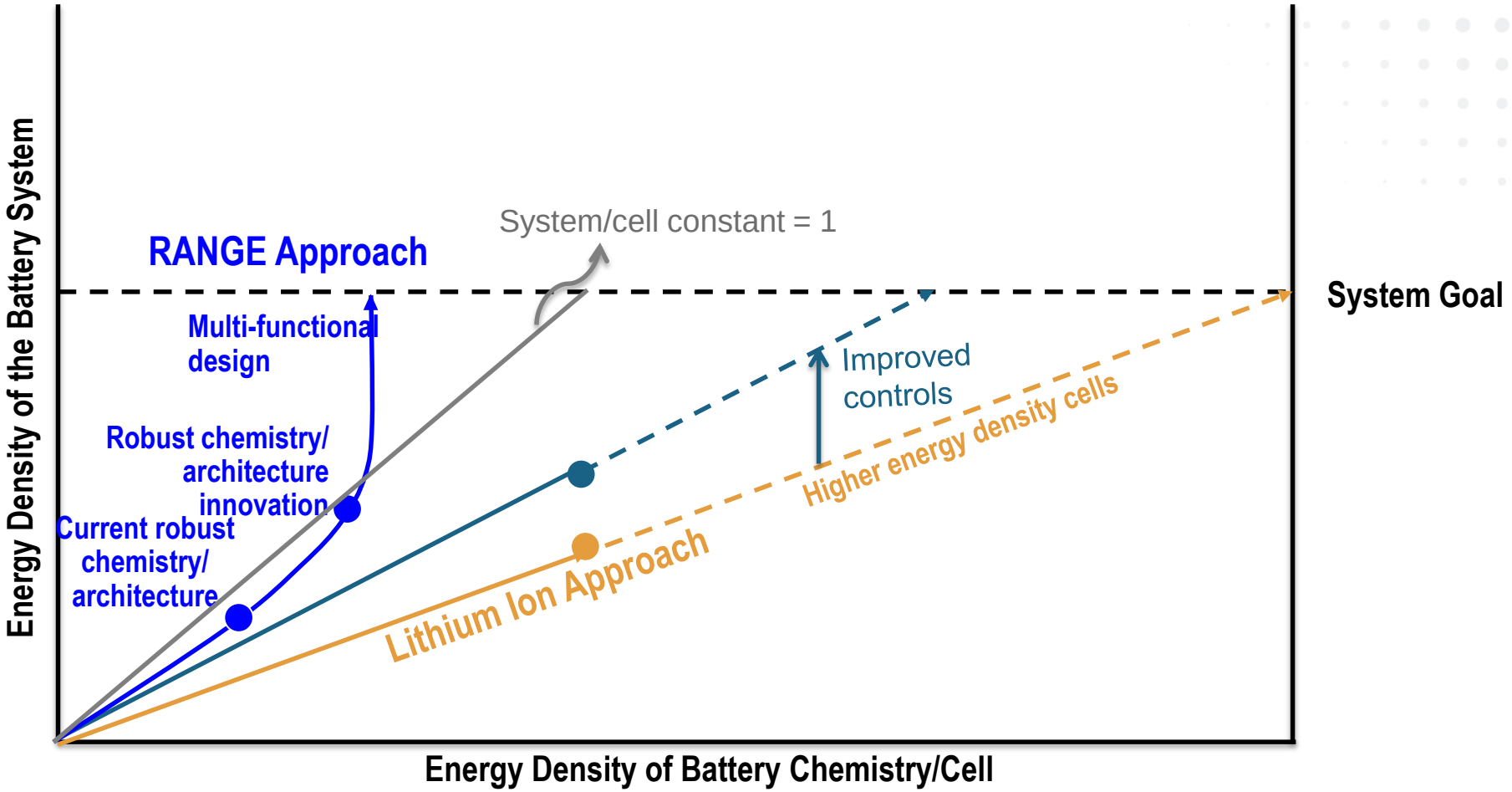


Vision of an Alternative Path to a Low-Cost EV

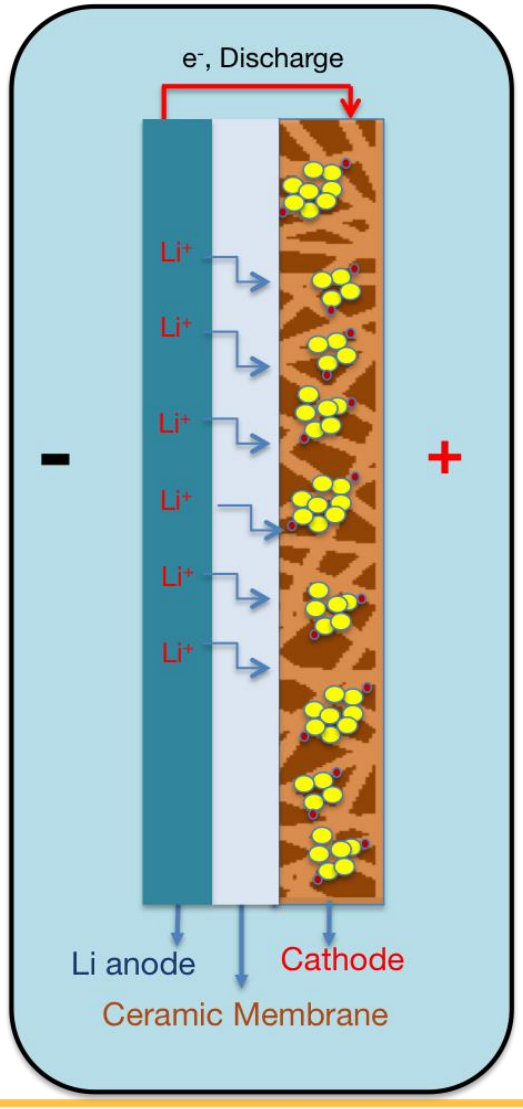


RANGE explores low-cost battery chemistries without added vehicle weight

RANGE Explores Whitespace in EV Battery Research

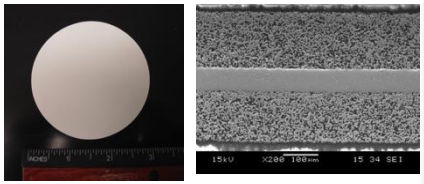


Technical Approach Example: Ceramatec



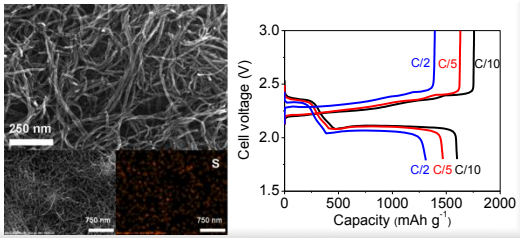
CERAMATEC
TOMORROW'S CERAMIC SYSTEMS

Development of non-porous planar
Li Super Ionic Conducting (LiSICON)
ceramic membrane with high conductivity.



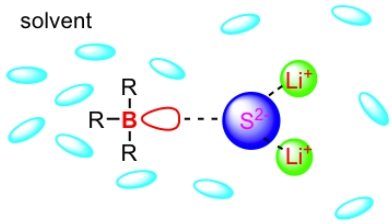
THE UNIVERSITY OF TEXAS AT AUSTIN

Sulfur-CNT
composite cathode



Argonne NATIONAL LABORATORY

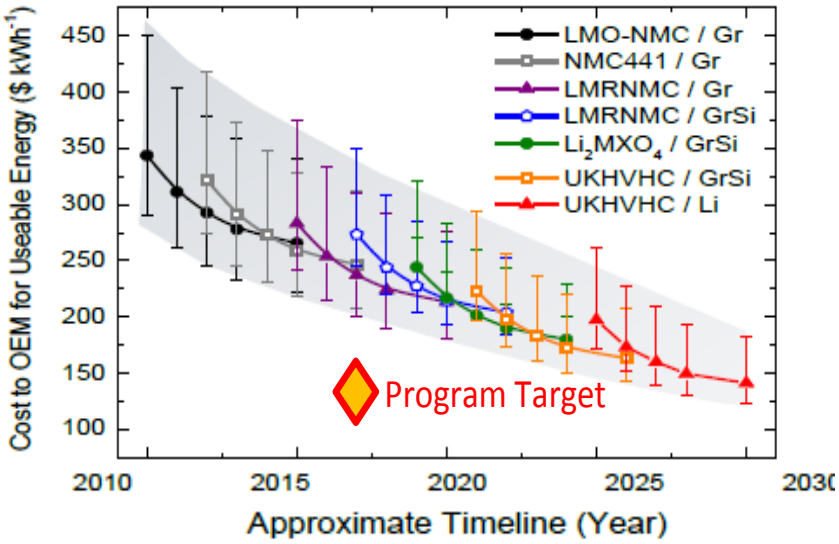
New solvent additive

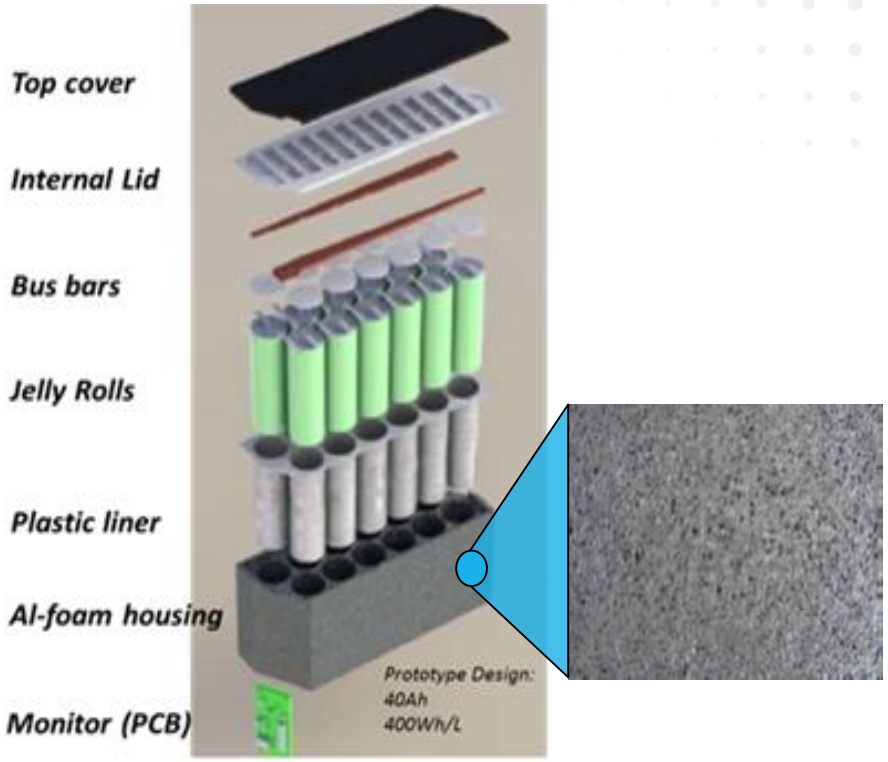


NISSAN

Cell testing, system modeling,
defining customer requirements

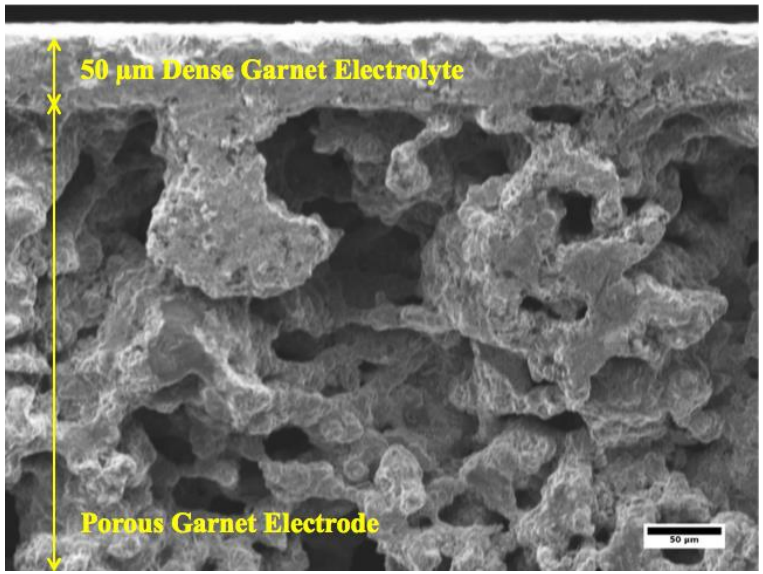
Technical Approach Example: Cadenza Innovation, LLC

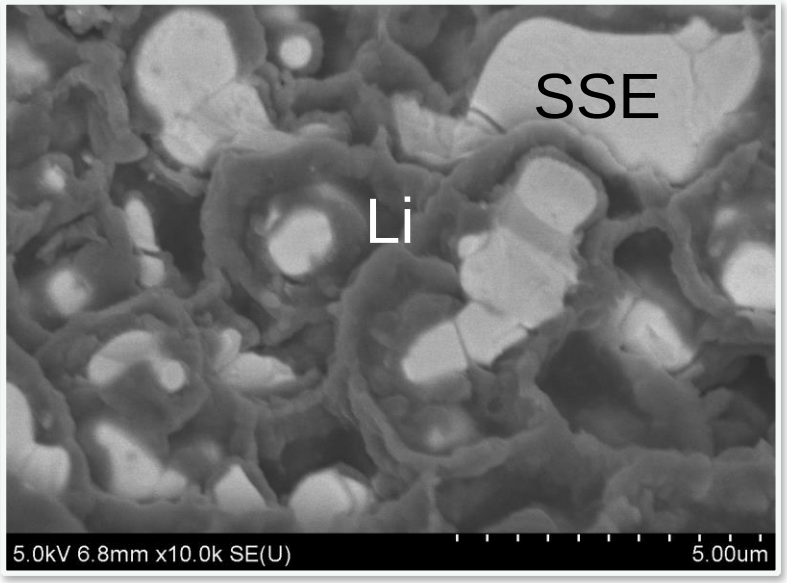




Team: cloteam llc, Magna Steyr Battery Systems NA, Chrysler/FIAT Group National Renewable Energy Laboratory (NREL), and MIT

Technical Approach Example: Univ. of Md.

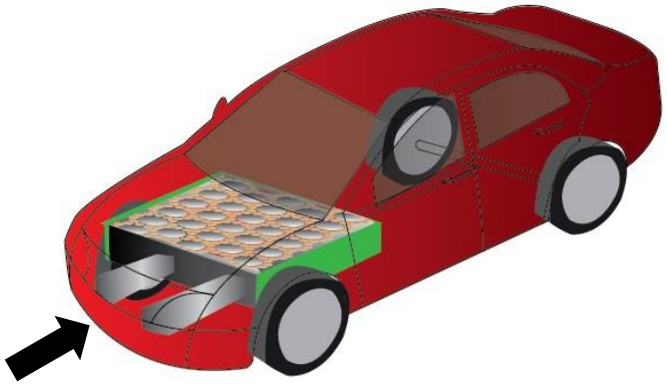




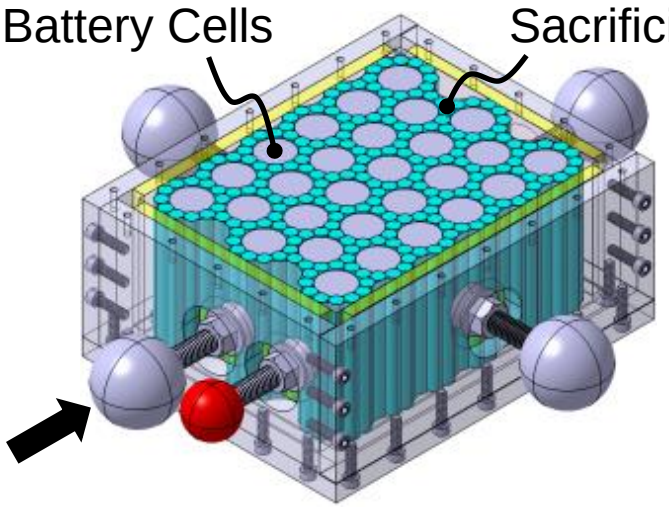
UNIVERSITY OF CALGARY

Demonstated cycling of high capacity lithium all solid state cell using garnet solid state electrolyte (SSE)

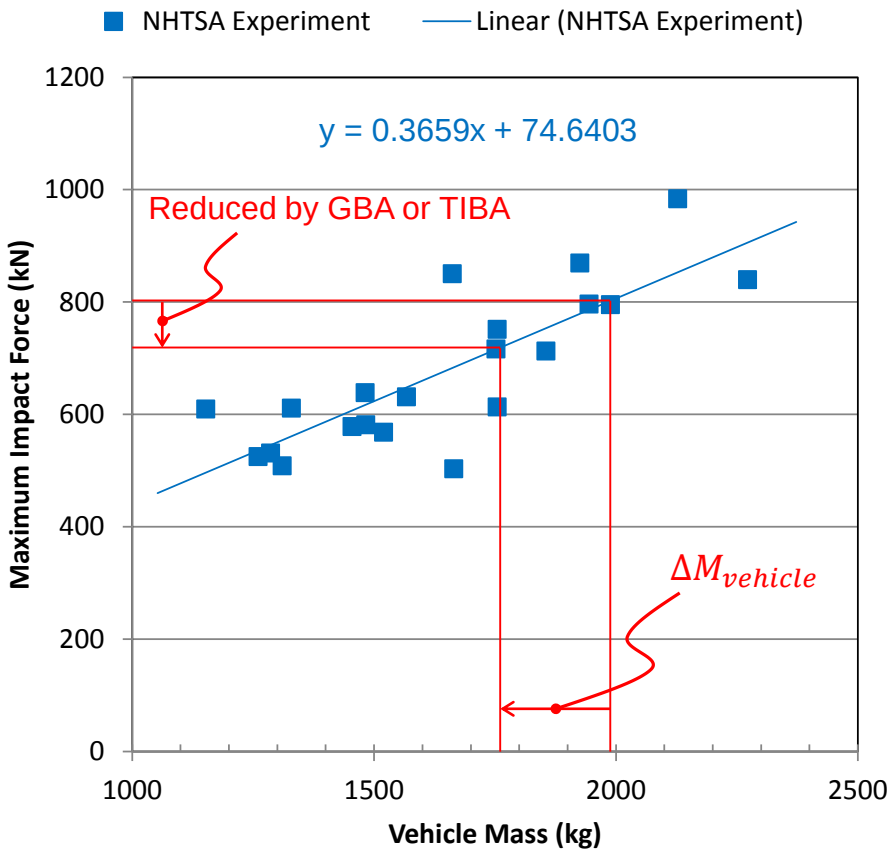
Technical Approach Example: Purdue Univ.



Granular Battery Assembly (GBA) Conceptual Sketch



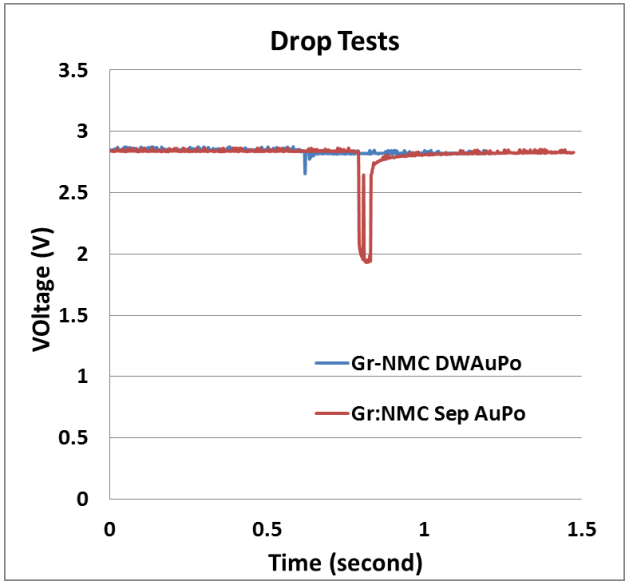
GBA Scaled-down Prototype

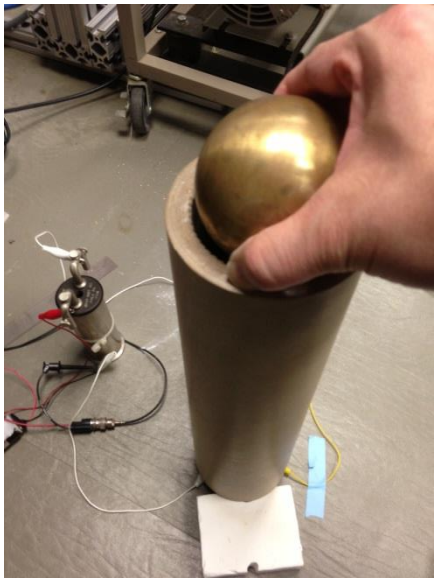


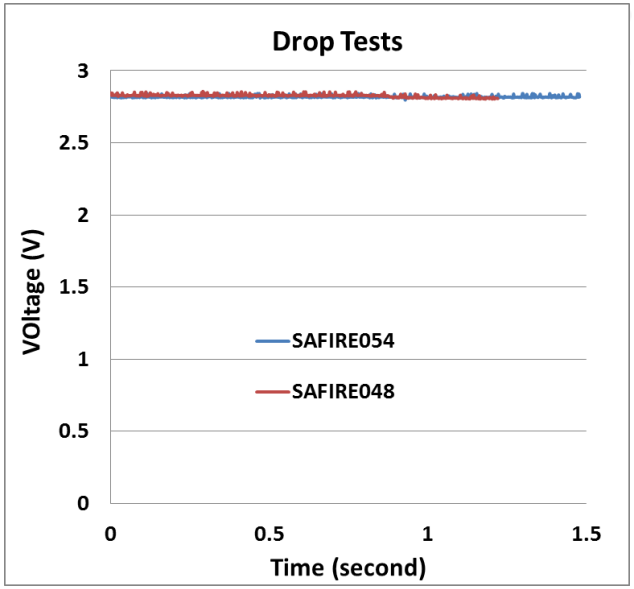
A slight reduction in peak impact force can lead to significant vehicle weight reduction.

Technical Approach Example: ORNL

Oak Ridge National Laboratory (ORNL)







Standard electrolyte

Shorting due to separator failure

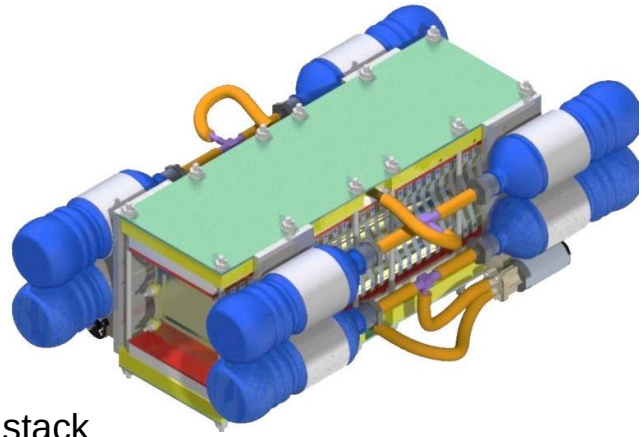
SAFIRE electrolyte

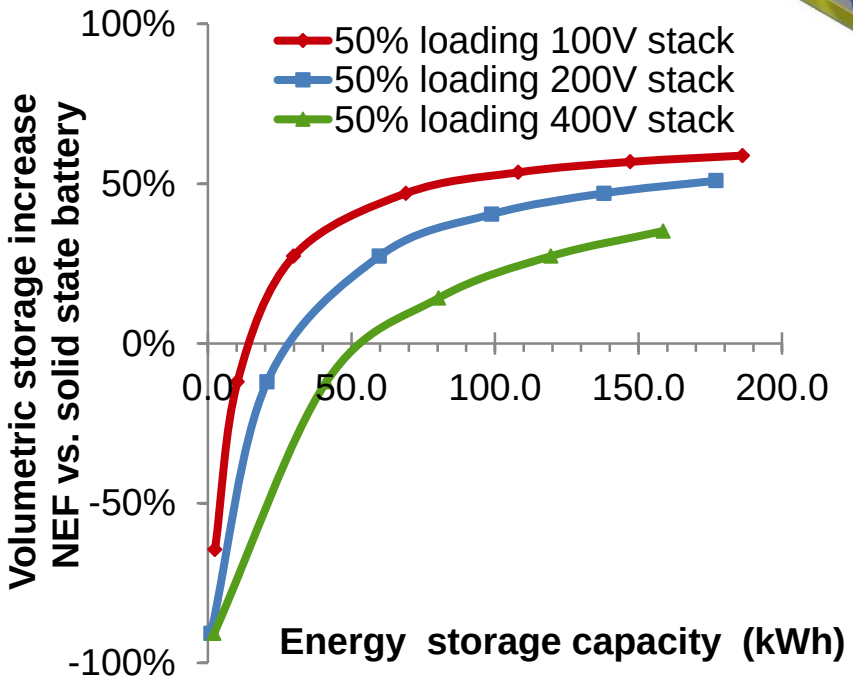
No shorts upon impact!

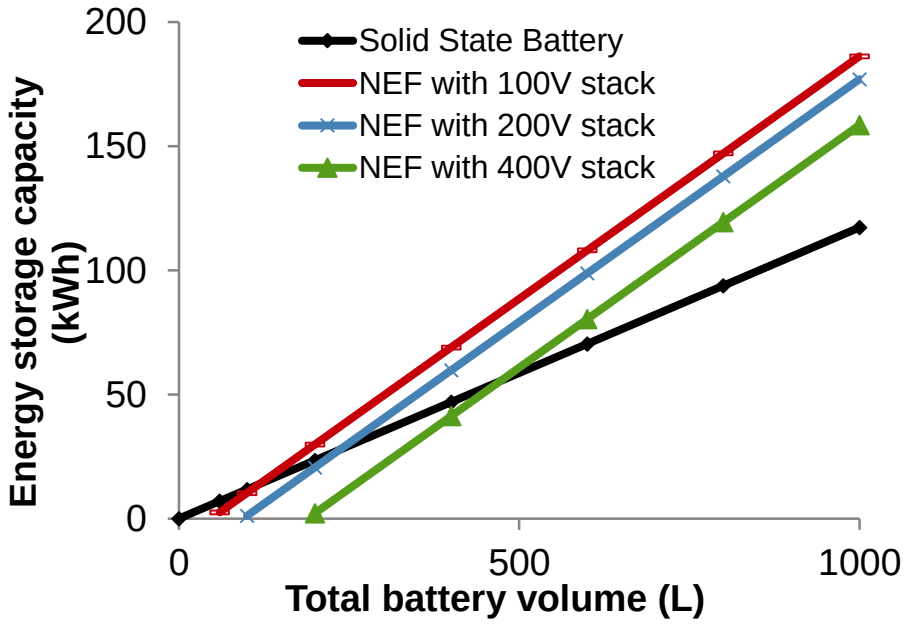
Technical Approach Example: IIT/ANL

Illinois Institute of Technology (IIT)/Argonne National Laboratory (ANL)

NEF Battery: high energy density solid state chemistries in pumpable format



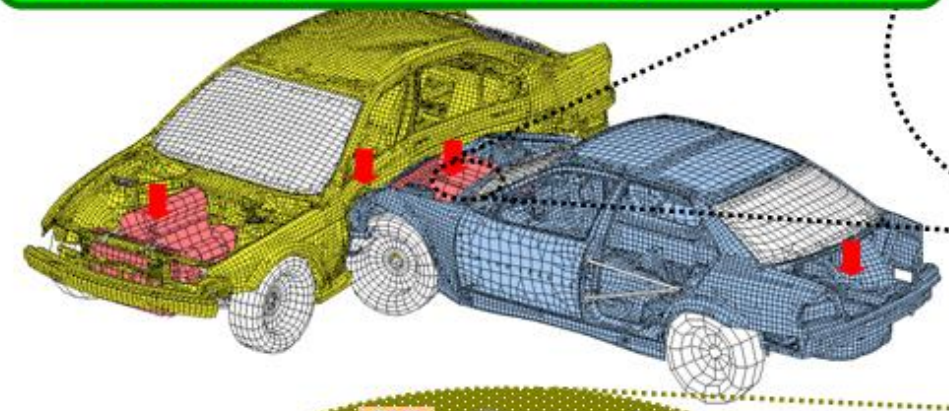


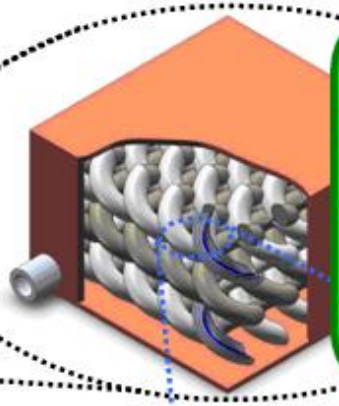


Technical Approach Example: UCSD

University of California San Diego (UCSD)

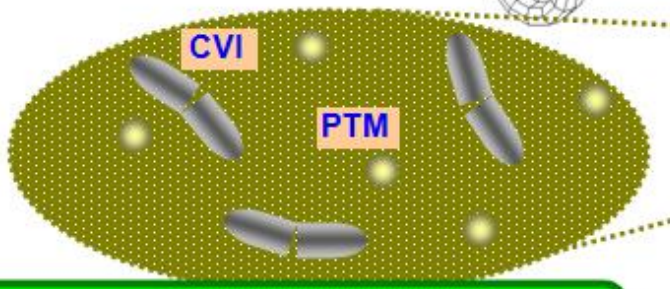
Vehicle level: Computer simulation to optimize structures and locations of multifunctional battery packs, which significantly saves cost and weight of auto frame.



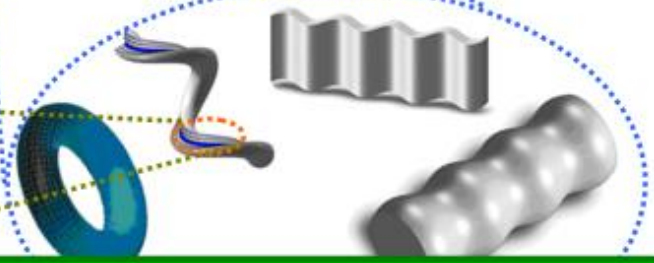


Module/pack level: Multifunctional arrays and trusses formed by cells

- In normal operation or mild collisions: structurally stable & load-carrying
- In a moderate collision: crash protection at the module/pack level; cells are undamaged & reusable
- In an intense collision: crash protection at all levels



Electrode level: Functional electrode (FE) arrests thermal runaway.



Cell level:

- Cells may be either "soft" (energy absorbing; e.g. spring-like or wavy-plate shaped) or "hard" (undamaged and reusable), depending on the intensity of collision and the functional requirements.
- Low-cost, minichannels based BTMS

RANGE Program

Aqueous

Robust Non-aqueous

Solid State

Multifunctional

cloteam, LLC

Reduced Emission Vehicles - Summary of ARPA-E's Efforts

Lightweighting:
METALS: reduce cost and production energy

Alternative Fuels:
MOVE: methane storage
REMOTE: methane conversion
Electrofuel: synthetic fuel
PETRO: alternative bio-fuel
REBELS: fuel cells for distributed generation, possibly suitable for transportation

Electrification:
BEEST: reduce battery weight and volume
AMPED: optimize the use of batteries
RANGE: robust storage to minimize vehicle system weight and cost
HEATS: thermal storage to reduce battery use
REACT: alternative magnetic materials

Climate Control:
DELTA: personal thermal comfort

Air travel for short-duration trips

Shorten travel times

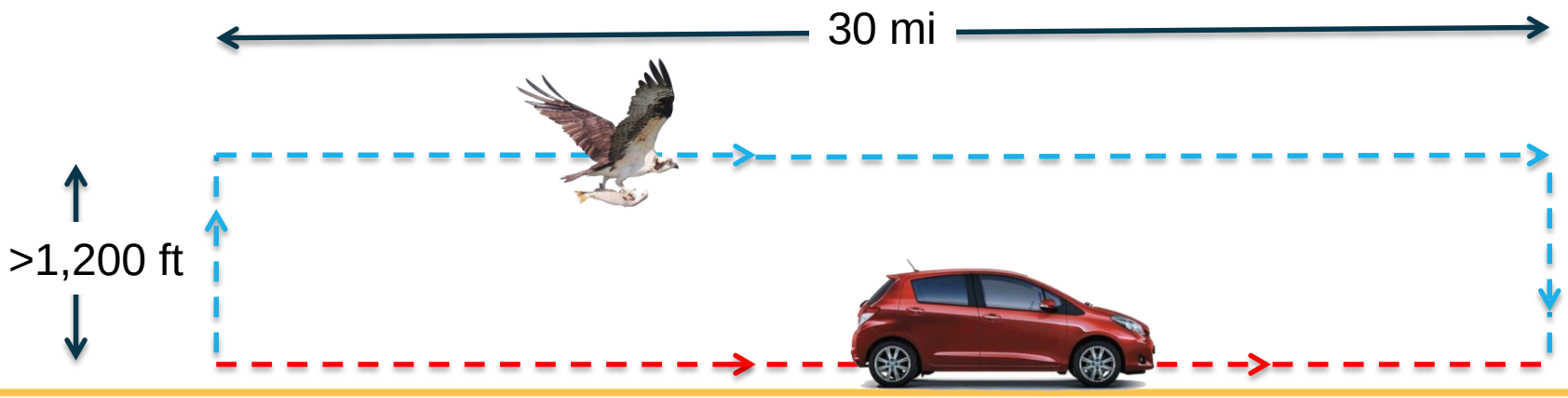
- Average speed: **>100 mph** vs. average city speed ~**30 mph**

Reduce idling and braking

Direct routes

Potential for safer travel

- In a collision of 1,500 lb car vs. 15,000 lb truck, who wins?



Move toward automation

Collision avoidance

↓

Vehicle-to-vehicle communication

↓

Autonomous vehicles

Sensing

Communication

Intelligent Controls

Fly-by-Wire

↓

Semi-autonomous unmanned aerial vehicle

↓

Fully autonomous aircraft

‘Flying cars’ are cool…
Would they consume much more energy?

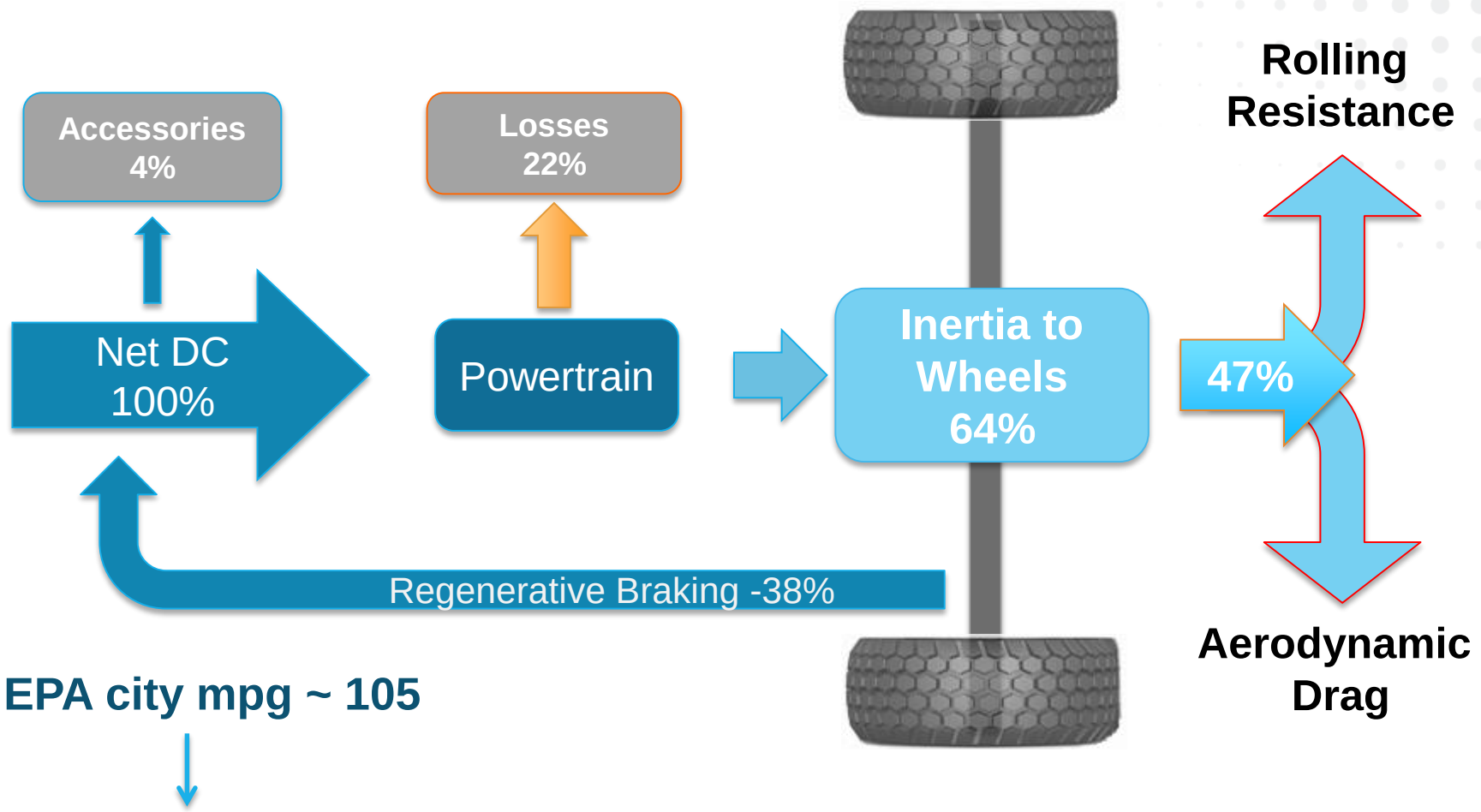
Moller M400


Terrafugia Transition


Terrafugia TF-X


Joby Aviation Monarch

Breakdown of electric vehicle losses



EPA city mpg ~ 105

65 mpg in heavy summer traffic

Nissan Leaf. Argonne National Laboratory

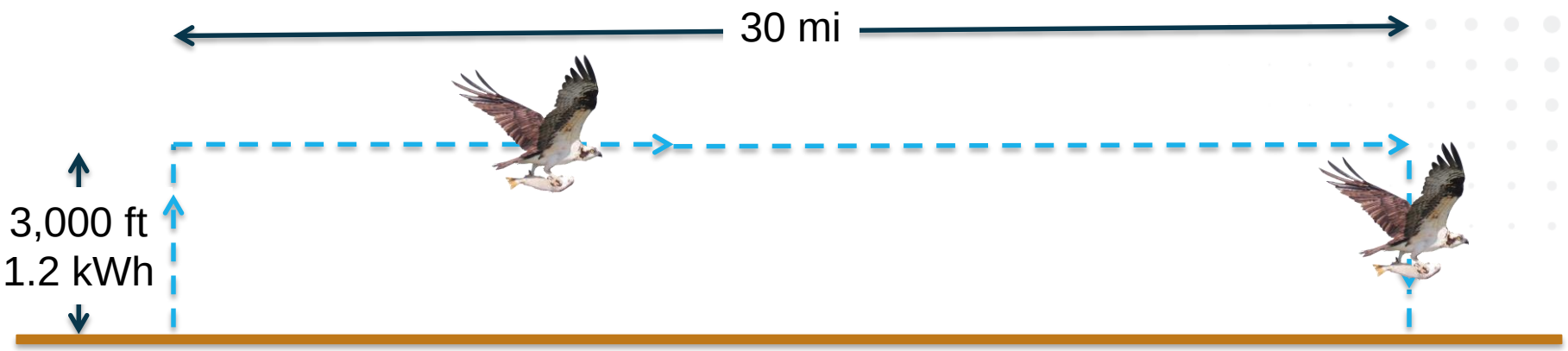
Current light aircraft

Sikorsky S-333™
- **MPG ~ 5**
- 2,460 lbs
- 4 person

Cirrus SR22
- **MPG ~ 16**
- 3,600 lbs
- 4 person

Camcopter® S-100 (UAV)
- **MPG ~ 8**
- 441 lbs

Estimation of MPG for VTOL



$$C_D = C_d + \frac{C_L^2}{p \times AR \times e_s}$$

$$F_D = \frac{1}{2} r S C_D v^2$$

Losses from drag in cruise

$$E = mgh$$

Potential energy of aircraft

Key assumptions:

1100 lb aircraft

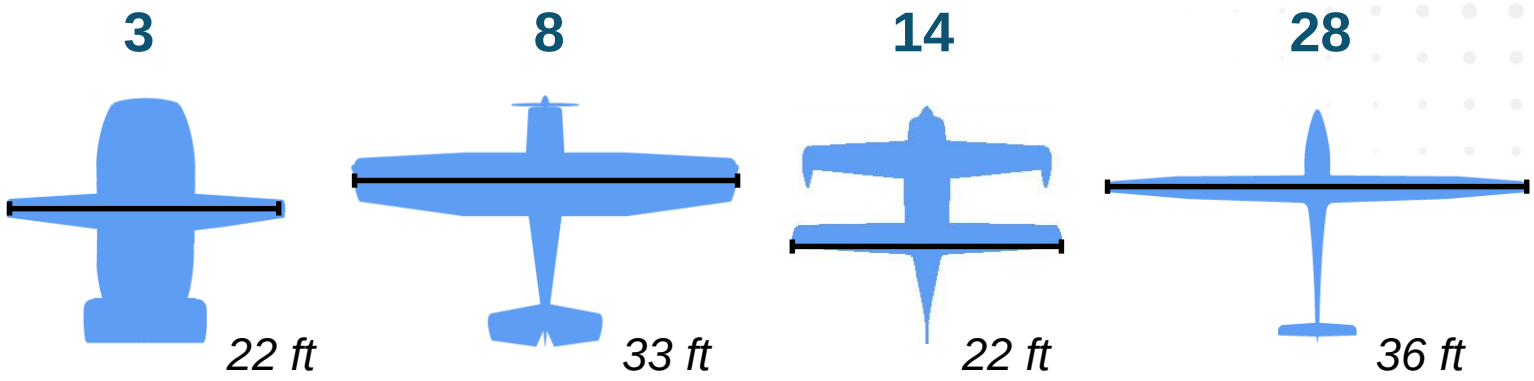
η_{EM} = 92%

$\eta_{battery}$ = 97%

η_{prop} = 80%

Estimation of MPG

Cruise Lift over Drag (L/D)



Cruise power	80 kW	45 kW	28 kW	16 kW
% mgh	5%	13%	20%	35%
% weight battery	94%	38%	24%	15%
MPG	**30**	**80**	**120**	**200**

For questions about ARPA-E's RANGE program, contact ping.liu@doe.hq.gov

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ARPA-E 2016 Summit
February 22-24, 2016
Gaylord National Convention Center
just outside Washington, DC.